SERVICE FATIGUE LIFE AS A FUNCTION OF RANDOM LOAD FACTORS

M. Bílý, V. Kliman[x]

Methods for the analysis of random process properties are introduced yielding either macroblocks of cycles or correlation theory statistical characteristics. These are further used for the service fatigue life estimation or experimental procedures with simulated processes. Some fatigue curves for various macroblock arrangement and various random processes are presented and discussed and certain recommendations are given.

INTRODUCTION

Despite the enormous effort devoted to fatigue process investigations it still remains a mystery mainly due to a vast number of interacting factors often conditioning unpredictable synergetic effects. From the practical point of view it is hardly possible to design the full factorial experiment or develop a universal model in order to investigate and explain partial and mutual influences of various factors on the resulting service fatigue life. Thus for the time being we rather face the situation when we are looking for some descriptive means of service load processes that could in the best way characterize their random behaviour or trying to correlate them with the resulting fatigue process and service fatigue life. Should a rigorous fatigue damage accumulation theory containing load process parameters, be available no problems with random process description would occur. Unfortunately this is not the case, as can be deduced from a number of fatigue damage accu-

---

[x] Institute of Materials and Machine Mechanics of the Slovak Academy of Sciences, Bratislava, Czechoslovak.

mulation hypotheses, and so different opinions on the relative importance of various characteristics of operating random processes must be taken into account.

RANDOM PROCESS ANALYSIS

The analysis of a random operating process can be carried out either by using the counting method (e.g. the rain flow method as the most frequent representative) giving a macroblock of sinuoidal cycles, or using the correlation theory of random processes giving a mean value, variance, autocorrelation function and power spectral density.

Although there are many disputable questions concerning the choice of one or the other method it would be waste of time to discuss their advantages and disadvantages. In general one should consider the aim of a specific analysis, technical possibilities of the equipment available, reliability of the process analysed, professional level of personnel involved, difficulties with the interpretation of results and other views. Further, the physical nature of the process analysed should be also taken into account. Most operating processes in fatigue and reliability applications are measured with resistance strain gauges producing strains which from the dawn of fatigue experiments have been recalculated to obtain operating stresses. Since the early sixties when a new concept of cyclic plasticity and Manson-Coffin fatigue curve was introduced, a direct application of the strain processes has been promoted, however, and there are objective reasons why this approach should be preferred. The most important of them is the experimentally verified fact that the scatter of calculated fatigue endurances based on the Manson-Coffin curve instead of the classical Wöhler (S/N) curve is smaller, ranging, e.g., for the Palmgren-Miner hypothesis somewhere between 0.6 - 1.5. Although it is sometimes supposed that the Wöhler and Manson-Coffin curves can be mutually transformed by means of the cyclic stress-strain curve (CSSC), numerous experiments suggest that in general it need not be true. Two fundamental differences may appear here, viz.

- the Wöhler curve experimentally determined under the load control sometimes exhibits a certain discontinuity between the high and low cycle ranges that is not observed in the Manson-Coffin curve (Figure 1),
- the CSSC which is reckoned to be the best characteristic of cyclic material behaviour and so is used for this transformation, is strongly influenced by the mean

level under load control whereas under strain control the strain cycle mean value rapidly relaxes to zero, having practically no influence on the resulting calculated curve (Figure 2); the experimentally determined Manson-Coffin curve depends, however, on the mean level.

SERVICE FATIGUE LIFE

Suppose that according to some analytical method the operating random process is now expressed in the form of a macroblock or is described by its statistical characteristics and let us use these results for either theoretical (based on the fatigue damage accumulation hypotheses) or experimental (based on simulated processes) estimation of fatigue endurance.

Macroblock of cycles

Since the 1930´s, when such an approach was coined by Gassner, it has become obvious that the sequence of blocks (load history) is another parameter which has an effect on the resulting fatigue life. Consequently, various recommendations have been proposed (ascending - descending, half way ascending - descending, random sequence of blocks or individual cycles) for experimental verifications and formulations of various fatigue damage accumulation hypotheses to account for this effect. Although the effect was not always positive, nevertheless, this load history can be reflected providing some suitable parameter, sufficiently well describing the macroblock arrangement, is found. Such a parameter may represent the hysteresis energy (the area of the hysteresis loop), characterizing the energy corresponding to one loading cycle ΔW and to the total macroblock as $W_m = \sum n_i \Delta W_i$, where n_i is the number of amplitudes at the ith load level.

Figure 3 compares the calculated hysteresis energy W_m with the experimentally determined energies for four differently arranged macroblocks a - d as a function of standard deviation RMS in each block. It can be seen that three macroblock arrangements give results comparable with the calculated values and only the arrangement a with the ascending blocks yields smaller values of W_m and thus makes smaller damage at the lowest stress levels. On the other hand the largest energy and consequently the most advanced fatigue damage belongs to randomly distributed cycles except at the highest load levels applied for which cyclic creep occurs.

These results suggest that for the most reliable laboratory verification of the service fatigue life based on a macroblock a randomly distributed sequence of cycles should be used. Such a macroblock is probably the most extreme representation of a service load, yielding the most severe damage compared with other loading hostories. Moreover, such a random arrangement of individual cycles is probably the closest approximation to the original random process.

At the same time this result shows that the damage calculation based on the hysteresis energy accumulation reasonably well corresponds to the experimental curves, because it takes into account not only the block sequence but also the influence of amplitudes below the fatigue limit (Kliman (1)).

Simulated random process

It is believed that a more adequate model of a random process will result when its statistical characteristics are respected such as the mean level, variance, probability density of amplitudes or peaks, autocorrelation function (power spectral density), probability density of transitions between ordinates or peaks, etc.

In general it can be stated that nowadays the estimation of any statistical characteristic of an operating stationary random process is fairly straightforward but its use is more problematic. An important step forward has been made, however, since the computer controlled electrohydraulic loading machines became available offering a real chance to investigate the influence of random processes with various statistical characteristics on the fatigue damage accumulation.

Without going into details one can summarize that the real time computer algorithms offer the possibility to simulate (Čačko, Bílý, Bukoveczky (2))

- any probability density function of ordinates,
- any power spectral density of a Gaussian process,
- any power spectral density of a random process with an arbitrary probability density function, and some others.

Some of these tests are now in progress at the MTS computer controlled loading machines but unfortunately for the time being only partial results can be shown, documenting certain experimentally verified facts.

The first conclusion can be derived from Figure 4 showing two sets of points, corresponding to fatigue lives of steel specimens loaded by a Gaussian (dots) and uniformly distributed (crosses) stationary random process. Although the power spectral density was kept constant in both cases (resembling to the power spectral density C in Figure 6) the results are markedly different suggesting that the Gaussian distribution is much more severe than the uniform one. A similar qualitative conclusion stems from Figure 5 (Hauer (3)) proving that the most severe loading is that with a Rayleigh distribution followed by a Gaussian and uniform ones but all of them being on the unsafe side with respect to the Wöhler curve. This is obviously a rather warning conclusion that can be partially explained by the influence of occasional random peaks forming "tales" of the statistical distributions as compared with the sinusoid (at the same time it suggests, however, that the RMS stress measure of the y-axis may not be the most representative parameter for the life description).

Other conclusion can be drawn from the results in Figure 6 obtained for various random processes characterized by three types of power spectral densities (covering the frequency range up to 17 cps) and three types of probability density functions (G - Gaussian, U - uniform, R - Rayleigh). Considering the legth of time required for this sort of experiments some of these curves were experimentally determined and some calculated only using the hysteresis energy approach (Kliman, Bílý (4)). It is seen that neither of these statistical characteristics can be neglected. Evidently the power spectral density which contains the power at higher frequencies is more agressive (the process with the power spectral density B, then A and finally C), as the corresponding process is faster when its effect is measured in time to failure. The normal probability density function yields in all cases the shortest life, then the Rayleigh distribution goes (which contradicts to Figure 5 where the Rayleigh distribution is the most agressive) and the uniform distribution gives the longest life (note that in certain cases this difference makes 2 - 3 orders and can be hardly explained by pure statistical considerations).

CONCLUSIONS

Considering that the Nature is truly random it is worth examining the fatigue process under random loading in order to make the gap between the laboratory tests and/or calculations, and the true service as narrow as possible.

On the other hand this sort of investigations and experiments require a highly sophisticated equipment (as usually computer controlled testers, measuring chains, computers with A/D converters, etc.), well trained personnel, means and time. Certainly they cannot be left to one laboratory but require a close cooperation of all those who are interested in these problems that are, moreover, highly actual. It might be even possible to organize a round robin EGF programme to look at our possibilities (including test facilities as suggested, e.g., by the Fatigue Task Group) or organize the appropriate Working Party. Even more, because of our limited possibilities to deal with non-stationary processes (except in simulation (2)) we artificially wash out their time-dependent properties although some preliminary experiments clearly prove that by doing this we move to the unsafe side.

REFERENCES

(1) Kliman, V., Int. J. Fatigue, Vol. 7., 1985, pp. 39 - 45.

(2) Čačko, J., Bílý, M. and Bukoveczky, J. "Random Processes: Measurement, Analysis and Simulation", Elsevier, Amsterdam, 1988.

(3) Hauer, V., Strojírenství, Vol. 35., 1985, pp. 180 - 184 (in Czech).

(4) Kliman, V. and Bílý, M., Mat. Sci. Engng, Vol. 68., 1984, pp. 11 - 18.

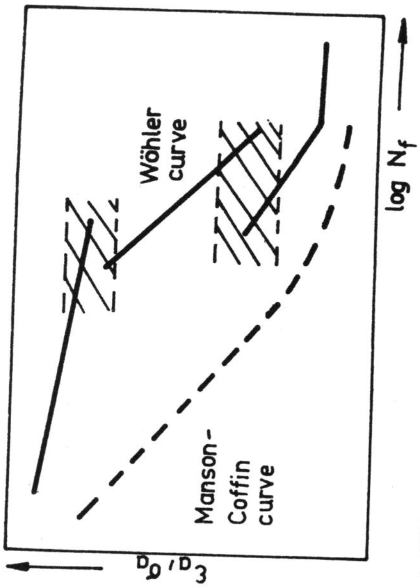

Figure 1 Wöhler and Manson-Coffin curves

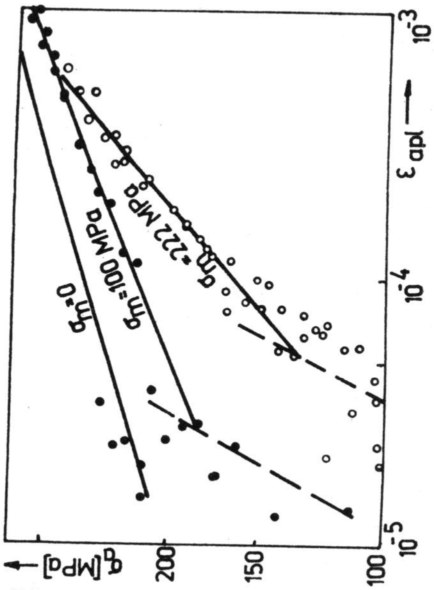

Figure 2a Load controlled cyclic stress-strain curve

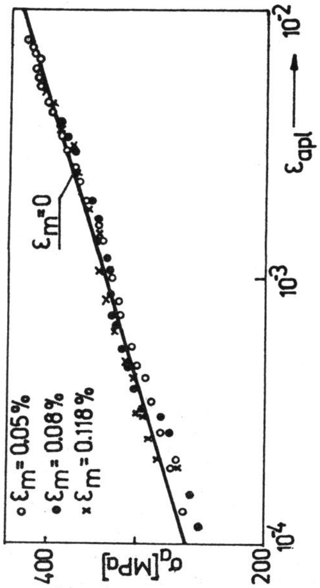

Figure 2b Strain controlled cyclic stress-strain curve

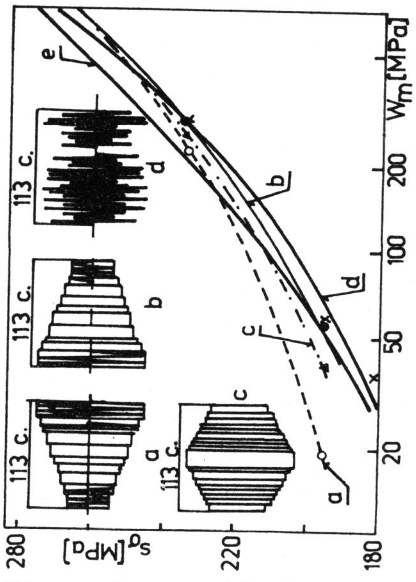

Figure 3 Macroblocks and corresponding energies